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LIQUID ICE PREVENTION AND CONTROL CHEMICALS FOR USE ON AIRFIELD PAVEMENTS

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July 1974

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ROBERT R. RICE
CAPTAIN USAF

JULY 1974

INTERIM REPORT FOR PERIOD JAN 70 TO DEC 73

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LIQUID ICE PREVENTION AND CONTROL CHEMICALS FOR USE ON AIRFIELD PAVEMENTS

by

Robert R. Rice
Captain USAF

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FOREWORD

This report summarizes work done between January 1970 and December 1973. The Project Officer was Captain Robert R. Rice.

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This technical report has been reviewed and is approved.

Robert R. Rice

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PREFACE

Evaluation of liquid chemicals for use as airfield pavement anti-icing/deicing agents was initiated by the Air Force Civil Engineering Center in 1970. Candidate liquid formulations were determined to be non-deleterious to aircraft and approved for field testing by the Air Force Materials Laboratory (AFML). Field evaluation of the AFML approved candidates was accomplished during the winter of 1970-71 at Kincheloe AFB MI. The purpose of the Kincheloe evaluation was to determine the effectiveness of liquid chemicals as anti-icing and deicing agents for use in airfield snow and ice removal and control operations. Simultaneously with the Kincheloe evaluation, information regarding the effects the successful candidates might have on the environment was requested from the Environmental Health Laboratory, Kelly AFB TX.

The requirement for determining the deleterious effect of liquid ice control chemicals on the several airfield pavement types was identified upon completion of the Kincheloe evaluation. This requirement led to freeze-thaw cycling tests on pavements performed for the Center by the US Army Cold Regions Research and Engineering Laboratory (CRREL), Hanover, NH. These tests were completed in September 1973. CRREL intends to publish a report for wide dissemination to interested agencies.

A final effort relative to Air Force use of liquid ice control chemicals is to be conducted by the 21st Civil Engineering Squadron, Elmendorf AFB AK, during the 1974-75 winter. The purpose of this effort is to finalize criteria for use of liquid formulations with mechanical snow and ice removal and control equipment under operational conditions. Upon completion of this effort, a report on liquid ice control chemical operations will be published and changes to AFM 91-14, Airfield and Base Snow and Ice Removal and Control, will be provided to HQ USAF for appropriate action.

The Project Officer wishes to express his appreciation to Mr Walter F Buhro, Superintendent of Pavements and Equipment; to Mr John B Crawford, Chief of Operations and Maintenance; to Mr Wayne Mansfield, Deputy Base Civil Engineer; and to Major Earl H Jones Jr, Base Civil Engineer, 449th Combat Support Group, Kincheloe AFB MI, for valuable assistance provided to AFCEC personnel during the Kincheloe AFB Ice Control Field Evaluation. Additionally, the Project Officer wishes to thank Mr A Stanley Dalton, 1st Lt Floyd F McClellen, and Sergeant David C [illegible]eno for the considerable support and valuable guidance they provided toward this effort.

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SECTION I

INTRODUCTION

1. BACKGROUND.

Snow and ice removal and control (SIRC) operations at northern and centrally located Air Force bases require a significant commitment of base civil engineer resources during winter months. SIRC equipment and operational techniques have been refined through the years by up-to-date designs and experience to a point of high efficiency. There remains, however, the chance of combining circumstances (i.e., storm severity, mechanical failure, etc) which can reduce the ability of SIRC personnel to cope with winter storms and to maintain runways and priority taxiways in a "bare pavement" condition, the goal of Air Force SIRC operations (1). In the past, SIRC personnel have used technical grade, Class 2, prilled (or shotted) urea conforming to Military Specification MIL-U-10866, and Grade B isopropyl alcohol procured under Federal Specification TT-I-735 as aids in ice control. These chemicals have a real but limited value since urea loses effectiveness below 15°F to 20°F, and isopropyl alcohol is deleterious to acrylic plastics normally used as aircraft canopies and windows. Alternate chemical means of preventing and controlling ice formation on priority airfield surfaces were clearly needed to either replace or supplement existing chemical aids.

2. OBJECTIVES.

The objectives of the study covered by this report were (a) to identify and evaluate for effectiveness as ice prevention and control agents any proprietary formulations which were determined to be non-deleterious to aircraft metals and plastics; (b) to determine if the commercial chemicals have any detrimental effects to airfield paving materials either by surface deterioration or by producing a surface with undesirable frictional qualities; and (c) to determine the nature of any environmental effects which may result from use of the new ice control agents in SIRC operations.

3. SCOPE.

Initially, the scope of this evaluation was to accomplish the first two objectives during field tests at Kincheloe AFB MI during the winter of 1970-71. As a result of this field evaluation, satisfaction of the second objective required a scope increase to include laboratory

freeze-thaw cycling of paving materials subjected to the several chemicals and application rates. The third objective was accomplished by the USAF Environmental Health Laboratory, Kelly AFB TX, upon request.

SECTION II

CHEMICAL EFFECTIVENESS TESTS

1. GENERAL.

Preparatory arrangements for the Ice Control Chemical Field Evaluation were begun by the Air Force Civil Engineering Center (AFCEC), then a division under the Directorate of Civil Engineering, HQ USAF, in July 1970. These preparations were in response to a portion of the FY 1970 Development Plan for Civil Engineering Technology, Subtask 7.3. Subtask 7.3 was deferred for lack of funds, and the ice control chemical evaluation portion was eventually assigned to AFCEC for in-house accomplishment.

At the request of AFCEC, Hq ADC approved(2) the test location, Kincheloe AFB MI, and the Air Force Materials Laboratory (AFML) supplied information concerning approved candidate ice control chemical formulations. The several chemicals which were then or subsequently approved by AFML as being non-deleterious to aircraft metals and plastics are presented in Table 1. All of these formulations could not be evaluated due to fund limitations. The Lynhurst Chemical Corporation product was excluded because of its similarity with Union Carbide's UCAR Runway Deicer and Allied's ARD-45(3). Allied Chemical Company's 70-42-1 was not tested because of its similarity with Monsanto's MCS-1082(4). (The Monsanto Corporation subsequently changed the designation of MSC-1082 to Santomelt 990 CR.) Neither of the Dow Chemical Company formulations were formally tested since they could not be procured and delivered in time to be extensively evaluated.

The test area locations were observed prior to the commencement of the field evaluation and judged satisfactory for the purposes of the test. The paved area selected, Taxiway 6, was constructed during World War II as the east-west runway of Kinrose AFB (name subsequently changed to Kincheloe AFB). The pavement is old, non-air entrained concrete. The area was selected because evaluation operations would not interfere with normal aircraft operation and only slightly with surface vehicle traffic. The test blocks were located on Taxiway 6 as indicated on the partial base map, Figure 1. The layout and dimensions of the test blocks are shown in Figure 2. Table 2 shows the assignment of chemicals to the several test blocks. Traffic cones were further used as markers to aid the test personnel and heavy equipment operators in identifying the test blocks during periods when the areas were snow or ice covered or during the night operations required during Phase II of the field evaluation.

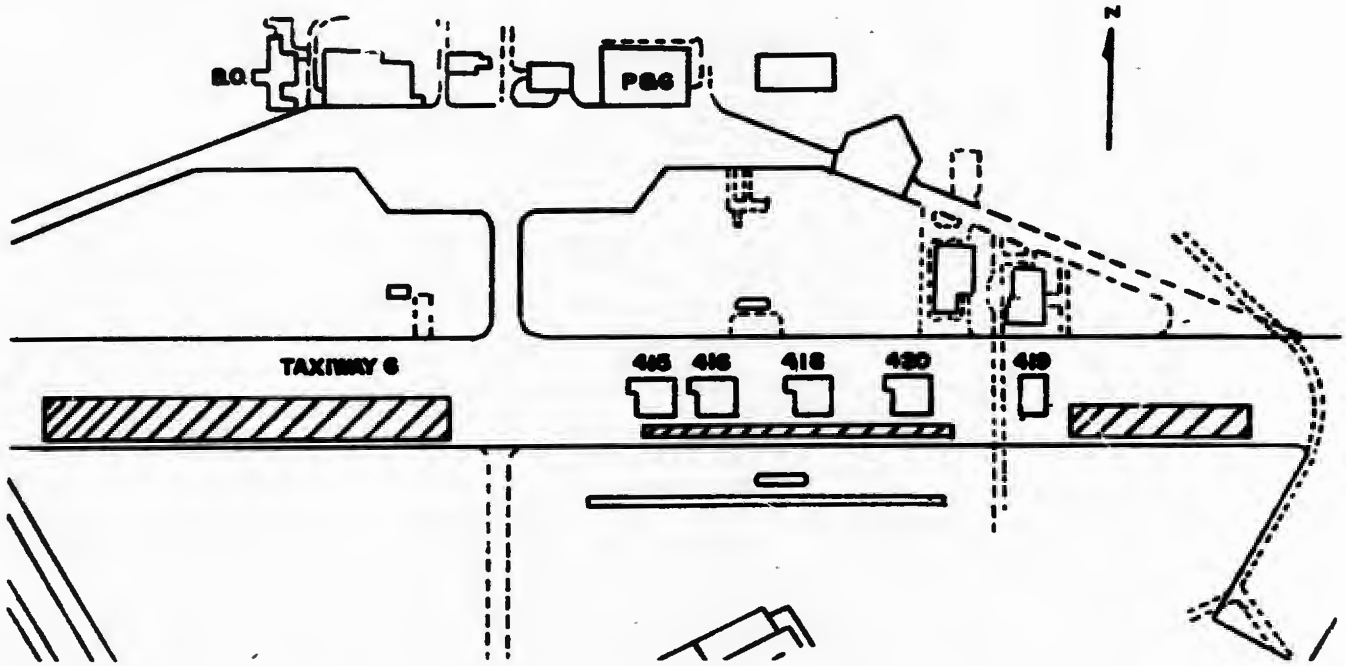
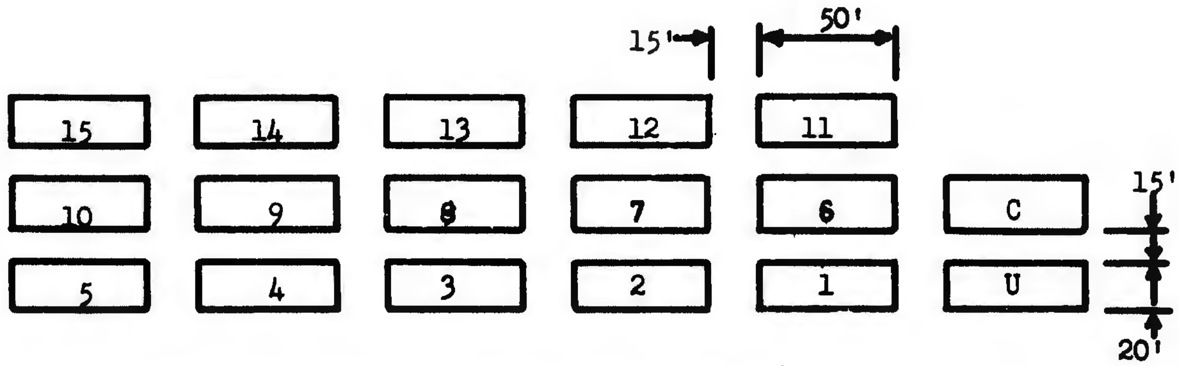
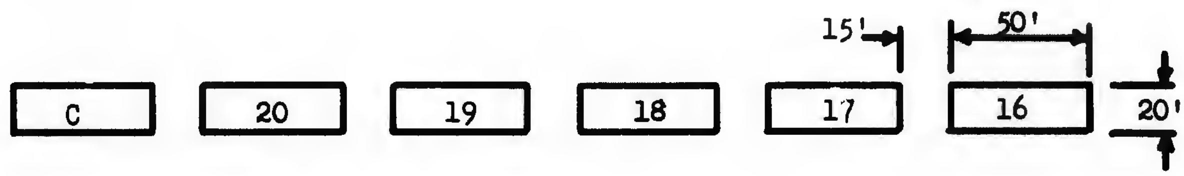


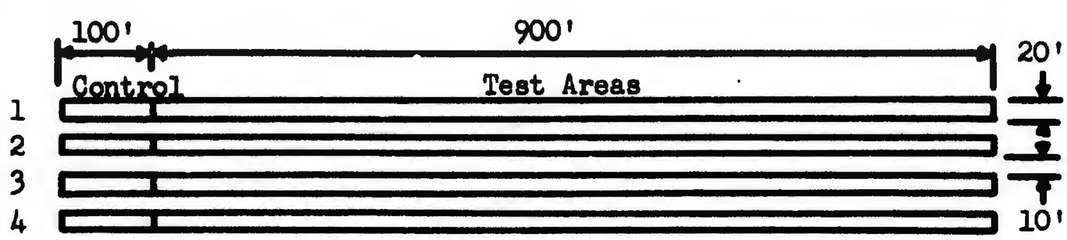
Figure 1. Test Location, Taxiway 6, Kincheloe AFB MI.



Phase I Test Area, South-East of Building 419



Phase I Test Area, South of Buildings
415, 416, 418 and 420



Phase II Test Area, West of Building 415

Figure 2. Test Block Layout and Identification.

TABLE 1. CHEMICALS APPROVED BY AFML FOR FIELD TESTING

Formulation	Manufacturer	Field Tested	AFML Approved	Ref
Urea	MIL-U-10866C	b	17 Jul 70	5
Defrosting Fluid	MIL-A-8243B	Yes	17 Jul 70	5
Runway Deicer	Union Carbide	Yes	17 Jul 70	5
ARD-45	Allied Chemical	Yes	6 Nov 70	6
70-42-1	Allied Chemical	No	6 Nov 70	6
LDR Deicing Fluid	Lyndhurst Chemical	No	8 Dec 70	7
MCS-1082[a]	Monsanto Corp	Yes	26 Jan 71	4
Formulation #24	Dow Chemical	No	25 Jan 71	4
Formulation #25	Dow Chemical	No	25 Jan 71	4

[a]Redesignated Santomelt 990 CR
[b]As a comparator chemical

TABLE 2. CHEMICAL ASSIGNMENT SCHEDULE

PHASE I ANTI-ICING/DEICING TEST BLOCK SCHEDULE							
Runway Deicer		ARD-45		Ethylene Glycol		MCS-1082[a]	
Block	Rate[b]	Block	Rate[b]	Block	Rate[b]	Block	Rate[b]
1	4.0	6	4.0	11	4.0	16	4.0
2	2.0	7	2.0	12	2.0	17	2.0
3	1.5	8	1.5	13	1.5	18	1.5
4	1.0	9	1.0	14	1.0	19	1.0
5	0.5	10	0.5	15	0.5	20	0.5
PHASE II ANTI-ICING/DEICING TEST BLOCK SCHEDULE							
Runway Deicer		ARD-45		Ethylene Glycol		MCS-1082[a]	
Block 1		Block 3		Block 4		Block 2	

[a]Redesignated Santomelt 990 CR
[b]Gallons per 1000 square feet

The equipment used during the field evaluation was obtained from several sources. These sources included the 4609th Civil Engineering Squadron, Kincheloe AFB MI; the Air Force Civil Engineering Center; and GSA, Columbus OH.

a. The station wagon, used as transportation for team members, as the tow vehicle for the Mu-Meter, and to transport the small miscellaneous test equipment items to and from the test site, was obtained from GSA.

b. The Mu-Meter was selected by AFCEC as the device to measure and record on a continuous basis the surface tractive characteristics of the test blocks. It was equipped with the event marker stylus and actuating bulb. Accessory equipment included two extra tires, mounted and balanced; the test board, required to check the machine calibration; and the circular slide rule to calculate average traction values of readings from the chart recorder box digital readout windows.

c. The water truck was provided by the 4609th CES, Kincheloe AFB, and was calibrated to determine the spray bar distribution rate. (See Appendix A)

d. Liquid chemicals were applied with a modified asphalt distributor calibrated for application rate (see Appendix B). This vehicle was furnished by AFCEC.

e. The 4609th CES provided inventory snow removal equipment and operators when requested by the team chief or the project officer and when snow removal operations on priority airfield areas would permit their use to aid the field evaluation. This equipment included the air-blast snow sweeper and 54,000 GVM carriers equipped with rollover and under-body snowplow blades.

f. Other miscellaneous equipment and supplies included pressure spray cans, five gallon military fuel cans, thermometers and thermometer shield, various measuring and mixing containers, pressurized cans of paint, a tape measure, traffic cones, and ice chipping tools.

2. PROCEDURES AND RATIONALE.

The purpose of the Phase I anti-icing and deicing tests was to collect a large amount of data on the relative performance of the several commercial formulations under varying ambient conditions and application rates. The Phase II anti-icing and deicing tests were designed to collect data on the use of SIRC equipment in conjunction with the chemicals. The test block locations and

application rates for each test block for both Phases I and II were as discussed previously in this report.

a. Phase I Deicing Tests. The procedures used during each daily series of tests are outlined below.

The test areas to be used were cleaned as much as possible, in coordination with other base SIRC operations, with the aid of snowplow under-body blades and air-blast runway sweepers assigned to the 4609th CES.

Once the test area was sufficiently cleaned, a Mu-Meter recording was obtained of all applicable test sites. This provided a comparative indication of each test surface's tractive characteristics to be used in the analysis process.

Water was then applied to the test blocks with the water truck in a series of passes until the desired ice thickness was obtained. The ice thickness utilized throughout each of the tests was based on the number of passes with the water truck and on ice thickness calculations once the truck had been calibrated. Water was applied in a series of passes, rather than in a single pass, to more closely approximate ice formed by naturally falling and freezing precipitation. It is realized that natural precipitation falls and freezes in a random manner with each drop splattering into a series of droplets which subsequently freeze. This phenomenon develops an ice sheet composed of many, very small, ice-crystal platelets. Because of the freezing of each of these platelets, the ice sheet formed is believed to be considerably more porous than is an ice sheet formed by freezing a layer of water. Ice formed from a compacted snow mass is known to be quite porous; however, no attempt was made to simulate ice of this type. An analysis of the water used to simulate natural ice is presented as Appendix C.

The surface temperature was obtained and recorded using a shielded thermometer, similar to that described in AFM 91-14.

Once ice was observed to have formed, a Mu-Meter recording of the surface tractive characteristics was obtained. These recordings were updated pericdically, though not at set intervals as was originally planned, due to the testing workload involved. The final Mu-Meter recording prior to application of chemical was used as characteristic of initial test surface conditions during analysis.

After the surface ice tractive characteristics were recorded, chemical was applied at the desired rate to each test block. Chemical application was accomplished by hand, using two-gallon pressure sprayers. The chemical was mixed to the dilution prescribed by the manufacturer, if required, and measured into the spray cans. The measured amount of chemical was then applied to the applicable test block as evenly as was possible using this technique.

As soon after chemical application as possible, consistent with test workload, a Mu-Meter trace of the test area was obtained. These recordings were then obtained periodically, again depending on workload requirements, at 15 to 20 minute intervals until base snow equipment and operators arrived.

Heavy SIRC equipment was requested to arrive at the test location about 30 minutes after chemical application. As soon as the equipment was available, it was used on the test blocks. Periodically, at about 15 minute intervals, additional Mu-Meter recordings were obtained to provide a progression of data for each test block.

Testing was concluded after about three hours or when the tractive characteristics as well as visual observation indicated the test blocks were reasonably clear of ice.

b. Phase I Anti-Icing Tests. In order to accomplish these anti-icing tests, the blocks were cleaned of surface ice and snow as much as possible, equipment availability and base workload permitting. Anti-icing tests were not run unless the surfaces were judged to be 90% free of ice. Snow was completely removed with the aid of air-blast sweepers.

Mu-Meter recordings were obtained after the area was cleaned and prior to applying chemical. This was required to determine if the chemicals significantly changed the tractive characteristics of the test surfaces.

Chemicals were then applied to the test areas at the desired rate, utilizing the two-gallon pressure sprayers and techniques described in the Phase I deicing test procedures.

The surface temperature was determined and recorded using a shielded thermometer.

After all test areas had been treated with chemical, the Mu-Meter was used to record the surface tractive

characteristics. Mu-Meter recordings were again obtained at intervals, consistent with test workload, until just before water was applied to the test areas.

Immediately after the water truck had traversed the test area with a single pass, another series of Mu-Meter recordings were logged to determine the time required for the water to freeze. These recordings were made at about 15-minute intervals. The tests were continued until the time when the Mu-Meter recordings dropped below 0.30 for all of the test areas.

As with the de-icing tests, the control test block was treated exactly as the chemical test blocks except that chemical was not applied. This procedure was used, as with the Phase I deicing tests, to nullify to the greatest extent possible, the effects of weather variances upon the test series.

c. Phase II Deicing Tests. At the time Phase I was completed, sufficient data on the effects of equipment usage in conjunction with the chemicals had been obtained. This portion of the field evaluation, therefore, was not pursued in Phase II except when natural icing or snow pack conditions were present. The time originally planned for these tests was rescheduled to extend the Phase II anti-icing tests.

The procedures utilized for deicing tests on the natural ice and snow pack were basically the same as for the Phase I deicing tests except that the modified asphalt distributor was used to apply the chemical.

d. Phase II Anti-Icing Tests. The procedures used for these tests were modified from those of the Phase I anti-icing tests in that smaller amounts of water were applied in each of several passes of the water distributor. This modification was made to determine the surface tractive characteristic changes as incremental amounts of water were applied under freezing conditions. Additionally, the two original purposes of this set of evaluations were retained, i.e., the amount of dilution to which the chemicals may be subjected before the surface traction deteriorates from freezing, and the use of snow equipment in conjunction with the chemical preparations.

The test surfaces were cleaned of snow and ice using base equipment as it was available.

A Mu-Meter recording was obtained for the test surface, along with the average traction value, to

determine the surface conditions prior to chemical application.

The chemical to be evaluated was then applied in a single pass and at a predetermined rate with the modified asphalt distributor.

Immediately following the chemical application, a Mu-Meter recording and an average traction value was obtained to indicate any increased slipperiness resulting from the application. This recording was followed by a second recording after about 15 minutes and just prior to the first application of water.

After the first application of water, a Mu-Meter recording was obtained again to detect the increase in surface slipperiness, which was followed by second and, at times, third Mu-Meter recordings at 15-minute intervals.

When it was judged that the water applied to the surface was not going to depress the surface slipperiness below 0.30 as measured by the Mu-Meter, an additional application of water was applied. This was repeated until the slipperiness of the test surface was depressed to below 0.30. At that time, an air-blast sweeper was requested to sweep the test surface.

Mu-Meter recordings and averages were then obtained. If the average traction value was raised above 0.50, an additional pass with the water truck was made, and the above steps were repeated. If the average traction value was not raised above 0.50, additional passes with the air-blast sweeper and the Mu-Meter were ordered.

The tests were concluded when the air-blast sweeper had made three passes without raising the surface tractive values above 0.50, or when other phenomena were judged to be interfering with the tests. An example of the latter was solar radiation on the surface causing the ice on the control section to melt.

Surface temperatures were recorded periodically throughout the anti-icing tests and recorded for later use during analysis.

Inventory snowplows with under-body blades were not utilized during this anti-icing evaluation series, except initially to clean the test surfaces.

3. ANALYSIS OF DATA.

Analysis of the Phase I deicing data was complicated by several factors: all chemicals showed a significant degree of variability between the day-to-day tests when used as deicing agents; the nature of interferences by conditions of weather, such as snow blowing across the test area, was probably quite significant; and the variability of using heavy snow removal equipment in conjunction with the tests as required by preplanning, required investigation. To appraise the data gathered during the Phase I deicing tests, it was necessary to objectively analyze the data in relation to the known parameters which influence the removal of ice from a paved surface. These parameters include surface temperature, ice thickness, chemical type and application rate, and use of snow removal equipment.

The analysis of anti-icing data obtained during the Phase II portions of the field evaluation was less complicated. The chemicals behaved in a much more predictable manner, since fewer influencing factors were involved in the tests.

a. Deicing Tests. Initially, the chronological sequence of events was graphically constructed to show the tractive characteristics of the chemical test block, the control test block and the difference between the two, i.e., chemical minus control, for each test. The chronology began at the time of initial chemical application. A test consisted of obtaining a set of data for a specific application rate of a specific chemical under conditions of surface temperature, ice thickness, and equipment usage. Once all graphic chronologies for a specific day were completed, all tests were subjectively compared in an attempt to determine the formulations which produced the best and the worst results and those which indicated intermediate results. This comparison revealed no clear indication regarding the relative merits of the deicing formulations under test conditions.

The data was then grouped to better judge the effectiveness of the formulations under the variables of chemical type, surface temperature, application rate, and equipment. From these groupings, the datum points were plotted on rectalinear paper, and straight lines were fitted by the least squares method. The first of the straight line plots was based on all datum points including those influenced by usage of heavy snow removal equipment. The second line was based on datum points excluding those obtained after SIRC equipment had been used. Additionally,

the upper and lower 90% confidence limits were determined for each line.

Tables 3, 4 and 5 summarize the results of the least squares line fit for the groupings indicated above. These tables show the slope of the line found according to the equation:

$$\mu - \mu_c = A + B\Delta t \qquad (1)$$

where: $\mu - \mu_c$ = the difference in traction values between the test block and the control block in time Δt (based on traction values which vary from 0.00 to 1.00).

A = the value of $\mu - \mu_c$ at Δt equal to 0.

Δt = the time lapse, in minutes, beginning with the start of chemical application.

B = the rate of change of $\mu - \mu_c$ with time.

The tables also show the upper and lower 90% confidence limits determined for the slope of the line (B) as well as the range between confidence limits. The smaller the value of the range, the more certain the reader can be of the mean value of the slope.

From Table 3, it can be seen that for a surface temperature range of greater than 15°F, prilled urea performed best when used with SIRC equipment. The mean value for the slope, 0.2659, indicates that a change in traction value of a chemically treated surface might be expected to increase by 0.26 on a 0 to 1.00 scale in 100 minutes (1 hour, 40 minutes). The difference between the upper and lower confidence limits, i.e., the range, indicates that the expected degree of variability is large, though not necessarily excessive. The ARD-45 at 4.0 gallons per 1000 square feet (gptsf), ethylene glycol at 4.0 gptsf, MCS-1082 (Santomelt 990 CR) at 1.5 gptsf, and Runway Deicer at 4.0 gptsf all performed with about the same degree of effectiveness, though with differences in variability. The ethylene glycol and MSC-1082 (Santomelt 990 CR) both performed better than the other liquid chemicals at any application rate and, surprisingly, better than at the 4.0 gptsf rate. The degrees of variability for both chemicals are fairly large, however.

Without equipment, Table 3 seems to indicate that MCS-1082 (Santomelt 990 CR) is the most effective. However, the large degree of variability associated with the 4.0, 2.0 and 1.5 gptsf application rates for this chemical make the mean values of the slope suspect. By judging the mean application rate values together with the range of variability, it appears that Runway Deicer performs as well or better at the 2.0 gptsf rate than urea applied at ten pounds per 1000 square feet.

Similar judgments may be made from Tables 4 and 5. From these tables, which depict the effectiveness of the chemicals between 0°F and 15°F, and below 0°F, respectively, Runway Deicer appears to be the most effective.

These tables point out the variability which existed in the data. This lack of consistent effectiveness serves to emphasize the effects that cloud cover, surface heating by solar radiation, blowing snow, wind chill, and other factors can have on SIRC operations.

b. Anti-Icing Tests. Analysis of the Phase II anti-icing data was straightforward and performed subjectively. As stated above, the chemicals performed in a much more predictable manner since fewer influencing factors affected the tests. It was necessary to clear the test area of all ice and snow to effectively evaluate the anti-icing capabilities of the several chemicals. Also, due to the approach of spring weather, it was necessary to perform the tests at night to avoid the surface heating effects of solar radiation.

Analysis was performed by graphically displaying the chronological sequence of events occurring during the tests. The Mu-Meter readings plotted on the graph readily identified the variations in surface traction during the chronology. Several of these displays are included in the appendixes. As may be seen from the graphs, application of chemical on dry pavements should have little effect on the tractive characteristics of the paved surface. (This is not necessarily true during deicing operations.) Another indication is that ice can be prevented from forming at the onset of freezing precipitation by the judicious use of liquid ice control chemicals. Air-blast sweepers are capable of removing the slush formed after chemical dilution, thus raising the surface frictional characteristics. After the slush has been removed by sweeping, additional chemical applications and sweepings are required to maintain the surface tractive characteristics at an acceptable level.

TABLE 3. Deicing Effectiveness of Chemicals for Surface Temperatures Greater than 15°F

CHEMICAL	APPLICATION RATE (gptsf)	VALUES OF B, LEAST SQUARES SLOPE							
		INCLUDES EQUIPMENT EFFECT				EXCLUDES EQUIPMENT EFFECT			
		MEAN VALUE	90% UCL[a]	90% LCL[b]	RANGE	MEAN VALUE	90% UCL[a]	90% LCL[b]	RANGE
Urea (prilled)	10.0#	0.2659	0.4288	0.1030	0.3258	0.1057	0.1184	0.0930	0.0254
ARD-45	4.0	0.1310	0.1783	0.0836	0.0947	0.0892	2.1397	-1.9613	4.1010
	2.0	0.0108	0.0512	-0.0303	0.0815	0.0710	0.6329	-0.4909	1.1238
	1.5	-0.0965	-0.0845	-0.1085	0.0240	-0.0965	-0.0845	-0.1085	0.0240
	1.0	-0.1417	0.6081	-0.8914	1.4995	-0.1417	0.6081	-0.8914	1.4995
Ethylene Glycol	4.0	0.1201	0.1285	0.1116	0.0169	0.0959	-0.5111	-0.3194	0.8305
	2.0	0.1927	0.3190	0.0666	0.2524	0.0730	4.9122	-4.7662	9.6784
MCS-1082[c]	4.0	-0.0524	-0.0354	-0.0694	0.0340	0.6424	1.0143	0.2705	0.7448
	2.0	0.2091	0.8474	-0.4292	1.2766	0.6032	1.2046	0.0017	1.2029
	1.5	0.1409	0.2660	0.0159	0.2511	0.3882	0.8798	-0.1034	0.9832
	1.0	0.0410	0.7371	-0.6551	1.3922	0.0254	0.2014	-0.1506	0.3520
Runway Deicer	4.0	0.1447	0.2206	0.0688	0.1518	0.1074	0.1680	0.0468	0.1212
	2.0	0.0920	0.0988	0.0852	0.0136	0.1370	0.1645	0.1095	0.0550
	1.5	-0.0900	-0.0893	-0.0907	0.0014	-0.0970	-0.0872	-0.1068	0.0196
	1.0	0.0144	0.0348	-0.0061	0.0409	0.0050	0.0152	-0.0053	0.0205

a. Upper Confidence Limit
b. Lower Confidence Limit
c. Redesignated Santomelt 990 CR

TABLE 4: Deicing Effectiveness of Chemicals for Surface Temperatures Between 0°F and 15°F

CHEMICAL	APPLICATION RATE (gptsf)	VALUES OF B, LEAST SQUARES SLOPE							
		INCLUDES EQUIPMENT EFFECT				EXCLUDES EQUIPMENT EFFECT			
		MEAN VALUE	90% UCL[a]	90% LCL[b]	RANGE	MEAN VALUE	90% UCL[a]	90% LCL[b]	RANGE
Urea (prilled)	10.0#	0.0700	0.1938	-0.0537	0.2475	0.0861	0.1774	-0.0052	0.1826
ARD-45	4.0	-0.0217	0.0441	-0.0874	0.1315	-0.0738	-0.0053	-0.1423	0.1370
	2.0	0.0012	0.2209	-0.2185	0.4394	0.0155	1.3712	-1.3403	2.7115
Ethylene Glycol	6.0	-0.0464	-0.0366	-0.0561	0.0195	-0.0464	-0.0366	-0.0561	0.0927
	4.0	-0.0234	0.2121	-0.2589	0.4710	-0.0792	2.1199	-2.2782	4.3981
	2.0	0.0303	0.1942	-0.1336	0.3278	0.1846	0.7435	-0.3743	1.1178
	1.5	-0.2987	-0.1902	-0.2272	0.0370	-0.0977	0.1599	-0.3552	0.5151
Runway Deicer	4.0	0.0930	0.1900	-0.0039	0.1939	0.0064	0.0526	-0.0398	0.0924
	2.0	0.1622	0.2061	0.1183	0.0878	0.1290	0.2428	0.0153	0.2275
	1.0	0.2270	0.2805	0.1735	0.1070	0.0543	0.1025	0.0060	0.0965

a. Upper Confidence Limit
b. Lower Confidence Limit

TABLE 5: Deicing Effectiveness of Chemicals for Surface Temperatures Less than 0°F

CHEMICAL	APPLICATION RATE (gptsf)	VALUES OF B. LEAST SQUARES SLOPE							
		INCLUDES EQUIPMENT EFFECT				EXCLUDES EQUIPMENT EFFECT			
		MEAN VALUE	90% UCL[a]	90% LCL[b]	RANGE	MEAN VALUE	90% UCL[a]	90% LCL[b]	RANGE
ARD-45	6.0	0.0839	0.1428	0.0250	0.1178	0.0630	0.6697	-0.5441	1.2138
	2.0	0.0719	0.0895	0.0543	0.0352	0.0603	0.1006	0.0199	0.0807
Ethylene Glycol	4.0	-0.0972	-0.0463	-0.1481	0.1018	-0.1914	-0.0672	-0.3156	0.2484
	2.0	-0.1471	-0.1201	-0.1740	0.0539	-0.2517	-0.1784	-0.3249	0.1465
Runway Deicer	4.0	0.1109	0.1738	0.0481	0.1357	-0.0160	0.4025	-0.4346	0.8371
	2.0	0.0293	0.3356	-0.2970	0.6526	-0.0530	0.3657	-0.4716	0.8373

a. Upper Confidence Limit
b. Lower Confidence Limit

4. RELATED EVALUATIONS.

During the winter of 1970-71, the same time period as tne AFCEC's Kincheloe AFB Ice Control Chemical Field Evaluation, the Port of New York Authority (PONYA) conducted tests of commercial liquid ice control chemicals at the LaGuardia and Clinton County Airports. Similarly, the Canadian Government's Ministry of Transport (MOT) conducted anti-icing and deicing tests of ice control chemicals, including prilled urea during the January through March 1972 time frame.

The report on the PONYA evaluation(8) indicated that while all of the chemicals tested were effective as deicing agents, no single chemical could be rated superior to the others. (The PONYA tests included products manufactured by Lyndhurst Chemical Corp, "LDR"; Allied Chemical Corp, "ARD-45"; Kaiser Aluminum and Chemical Corp, "ISOLV"; and Union Carbide Corporation, "UCAR Runway De-Icer.") The MOT report(9) referred to above reported essentially the same finding, but also indicated that urea was more effective than the liquid chemicals at temperatures near the freezing point of water. (The MOT evaluation considered Lyndhurst's "LDR"; Kaiser's "ISOLV"; Union Carbide's "UCAR Runway De-Icer"; and Monsanto Chemical Corporation's "Santomelt 990 CR.")

The PONYA report concluded that application of full concentration chemical on a "clean" dry pavement would reduce the dry pavement coefficient of friction by 15 to 20 per cent, while a 50% water diluted chemical solution on dry pavement or a full strength chemical on wet pavement would have little or no effect on the pavement coefficient of friction. PONYA defined a "clean" pavement as that which is not contaminated by "rubber, sand, fuel, oils, carbon soot or like deposits normally experienced on moderately to heavily used airport runways, taxiways and ramps--especially by jet aircraft." The MOT report indicated a pavement surface coefficient of friction drop of from 10 to 43 per cent when liquid anti-icers were applied. The MOT report did not indicate the chemical dilution, if any, or whether the bare pavement was wet or dry. The MOT attributed the depression in coefficient of friction to the viscosity characteristics of the chemicals which increase with decreasing temperatures. In other words, the lower the surface temperature, the slicker the pavement surface when treated with liquid ice control chemicals. Experience obtained from the Kincheloe AFB anti-icing tests did not include such radical depressions in surface tractive characteristics. The Kincheloe AFB tests were conducted on "clean" pavement, however, and that may

explain why significant depressions of surface tractive characteristics were not observed during the anti-icing evaluation.

The variation in experience as reported by PONYA and MOT with that obtained during the Kincheloe AFB evaluation indicates that precautions should be taken against sudden, unexpected deterioration of surface tractive characteristics during SIRC operations. To provide a precautionary measure, SIRC managers should test the chemicals on a small portion of the surface to be treated before deicing or anti-icing operations proceed further. The SIRC test area should be the width of the application equipment and about 200 feet in length. Some method to determine the slipperiness of the treated test surface versus the slipperiness of adjacent untreated surfaces should be applied. In lieu of a Mu-Meter or a Diagonal Braking Vehicle, the James Brake Decelerometer may be a useful indicator of this relative slipperiness. It must be remembered, however, that the decelerometer is not suitable to indicate aircraft stopping distances on wet surfaces. Another method may be the comparison of the lengths of skids to a full stop from, say, 20 mph. Other locally devised methods may be acceptable. Any method used should be acceptable to local base operations personnel. Assistance in developing the test procedures may be available from base law enforcement personnel. If the decelerometer readings or skid lengths are approximately equal (i.e., say ± 10%), then the frictional characteristics of the test surface are not appreciably degraded.

SECTION III

ASSOCIATED COMPATIBILITIES

1. AIRCRAFT COMPATIBILITY.

The Air Force Materials Laboratory (AFML) is responsible for insuring that chemicals used by the Air Force do not corrode aircraft. In this capacity, the AFML has published Military Specifications MIL-D-83411 (USAF), Deicer/Anti-Icer Fluid (For Runways and Taxiways). As part of this specification, they maintain a Qualified Products List (QPL) of commercial liquid ice control chemicals which have been tested and found to be non-deleterious to aircraft components. Proprietary chemicals which do not appear on the QPL should not be used for ice control operations on airfield pavements. Information pertaining to qualification of commercial ice control chemicals may be obtained from AFML/MXA, Wright-Patterson AFB OH 45433.

The AFML has also recommended(5) that the ethylene glycol based chemical procured under specification MIL-A-8243, (Aircraft) Anti-icing and Deicing-Defrosting Fluid, be used as an airfield ice control agent. Should shortages in available quantities of ethylene glycols exist, as was the case in December 1973, it may be desirable to assign normal operations priorities on the use of MIL-A-8243 fluids to aircraft ice control. In an emergency situation, however, normal priorities should be removed so that mission accomplishment can be achieved.

2. PAVEMENT COMPATIBILITY.

As a result of increased rates of pavement spalling observed during the Kincheloe AFB Ice Control Chemical Field Evaluation, the US Army Cold Regions Research and Engineering Laboratory (CRREL), Hanover NH, was commissioned to investigate the effects of ice control chemicals on airfield pavements. This investigation consisted of accelerated freeze-thaw tests on a variety of runway paving materials exposed to several liquid anti-icing/deicing formulations. The paving materials used in these tests included old and new air entrained portland cement concrete (PCC), old and new non-air entrained PCC, old and new asphaltic concrete, old and new tar-rubber concrete, and porous friction asphalt.

The CRREL final report(10) indicated that:

a. Asphaltic, tar-rubber and porous asphalt concretes were not significantly affected as a result of 60 freeze-thaw cycles. During testing, the pavement specimens were subjected to liquid chemical ice control solutions equivalent to application rates of 1.0 gallons per 1000 square feet and 2.0 gallons per 1000 square feet.

b. Portland cement concretes were significantly affected as a result of the same stresses as were applied to bituminous test specimens. Newer test specimens (cured for 30 days prior to testing) were deteriorated more than the older specimens, and non-air entrained specimens were damaged much more than air entrained specimens.

There are four variables which are expected to influence the rate of surface deterioration when a pavement is subjected to ice control operations. These variables are pavement type and age, chemical type and application rate, number of freeze-thaw cycles applied, and mechanical abrasion. The last variable, mechanical abrasion, was not addressed in the CRREL tests, though serious considerations were given to including it as one of the variables to be investigated.

Mechanical abrasion, in the form of pressurized scraping and high-speed brushing of ice and snow from the pavement surface, is the most commonly employed form of SIRC in the Air Force. This abrasion, either through an ice cushion or applied directly to the pavement surface, will further weaken and cause surface spalling along fracture planes previously weakened from freeze-thaw cycling. It is reasonable to conclude that mechanical abrasion will increase the deterioration rate of pavement surfaces subjected to ice control chemical treatment or to chemically induced freeze-thaw cycling.

As a result of these findings, it is concluded that:

a. Ice control chemicals should not be used on non-air entrained portland cement concretes.

b. Use of chemicals on air entrained portland cement concretes should be minimized commensurate with operational requirements.

c. Applications of chemicals on asphaltic, tar-rubber, and porous asphalt concretes should be limited by the economic balance between chemical and mechanical methods of ice removal and control.

3. ENVIRONMENTAL COMPATIBILITY.

All ice control chemicals are directly toxic to fish and other aquatic life at elevated concentrations. The Environmental Health Laboratory, Kelly AFB TX, reports toxicity to aquatic life at concentrations above 10,000 milligrams per liter (mg/l) for urea(11), above 5,000 mg/l for glycols(11), and above 500 mg/l for formamide based deicers (12). It is very unlikely that normal or even emergency runway ice control operations will result in chemical concentrations in receiving waters (i.e., a lake or stream) which exceed these levels. Four gallons of deicer applied to 1000 square feet of surface which is covered with 1/4 inch of ice will result in a concentration of about 28 mg/l chemical in the melt water. This melt water will not normally be discharged directly to a receiving water. Normally, it will be diluted with melt water from snow or ice adjacent to the runway.

Ice control chemicals become incompatible with a receiving water which supports aquatic life when the chemical is biodegraded by microorganisms. Ureas biodegrade to ammonia, which is highly toxic to fish at concentrations of about 1.0 mg/l, depending on the pH of the water(13).

Additionally, urea is a source of nitrogen nutrient, which stimulates algal growths resulting in increased organic content of the receiving water(11).

Glycols biodegrade readily in a natural receiving water(11). This nutrient source permits significant increases in microorganism populations which, as they metabolize, increase their demand for oxygen and depress the dissolved oxygen content of the water. If the level of oxygen is depressed sufficiently, fish and other aquatic life will be suffocated. The level of dissolved oxygen in waters required to support life is dependent on the animal species, the water temperature, prior acclimatization of the species, concentrations of other impurities, and other factors(13).

The products of microbial degradation of formamide were found to be 45 times more toxic to aquatic life than the unmetabolized formamide deicer, and one of the biodegradation products of formamide is ammonia(12). As stated above, ammonia is toxic to fish at concentrations of about 1.0 mg/l.

As a result of their work to determine the potential impact of liquid anti-icing and deicing on the environment, the Kelly AFB Environmental Health Laboratory has made several recommendations concerning their use(11,12). These recommendations are quoted as follows:

a. "Whenever possible, water containing urea or glycol deicers should not be discharged directly to a stream.

b. "Run-off from runways treated with urea should be diverted to holding ponds where one of the following steps should be taken if possible:

(1) "Use the waters for irrigation or spray onto the soil. The urea is an excellent fertilizer. When applied to soil, the nitrogen compounds will bind to the soil.

(2) "Aerate the pond with a surface aerator. If the urea nitrogen is oxidized to nitrates in the pond, the waters (with the low nitrogenous BOD) could be slowly released to the stream with the least detrimental effect.

(3) "If a sewage treatment plant that achieves a high degree of nitrification is available, pump the deicer solution from the holding basin to the plant.

c. "Facilities for transfer of waste to a treatment plant should be provided where glycol deicers are used on aircraft.

d. "Formamide deicers are environmentally less desirable than the urea and glycol deicers currently in use. Urea and glycol deicers should continue to be used until better alternatives are available.

e. "Prior to the use of any deicers, commanders should be aware of environmental pollution problems so that these can be considered with the urgency of the mission.

f. "Research to find deicers that have less detrimental impact on the environment is strongly recommended."

The above quotes stress the Environmental Health Laboratory's concern regarding the pollution potential of urea, glycol and formamide anti-icing and deicing solutions. These recommendations must be considered individually at each base, and they should be stressed or tempered depending on the base's geography and climate. Chemical usage will more seriously impact a base which discharges snow melt water runoff directly into a stream than it will a base where the melt water seeps into the ground. Similarly, a base which receives 100 inches annual snowfall will be impacted less than a base receiving 10 inches (assuming the same annual amount of deicer applied to the runway).

Each base should determine the potential for environmental impact from the use of chemical ice control formulations for their specific climatic, topographic, and geographic conditions. Additionally, an environmental assessment covering the use of ice control chemicals should be made part of the base snow removal plan.

SECTION IV

APPLICATION EQUIPMENT

Equipment used for applying liquid ice control chemicals may be of commercial or local design and, if possible, have dual application, i.e., ice control operations during the winter and insecticide/liquid fertilizer applications during the summer. Several manufacturers of agricultural spray equipment exist which will be capable of providing this equipment.

An applicator equipped with a 1000 gallon tank will apply 4 gallons of chemical per 1000 square feet in a 25-foot width to 10,000 feet of runway. The applicator should be equipped with a positive displacement pump capable of delivering up to at least 88 gallons of fluid per minute. The pump should be a variable type so that the flow may be easily changed to accommodate the several application rates required for ice control chemicals. A pump driven by a press wheel will deliver a constant application rate (i.e., gallons per 1000 square feet) once the rate has been selected, regardless of the vehicle speed. Table 6 indicates the relationships between chemical application rate, application speed, and pump delivery rate for a 25-foot spray bar.

The spray boom should be hinged to permit folding against the applicator sides when the equipment is being towed to and from the work site. The boom length may be selected to suit local requirements. It is noted, however, that a 1000 gallon applicator equipped with a 50-foot boom will treat only 5000 linear feet of runway at the rate of 4 gallons per 1000 square feet.

The height of the nozzles above the pavement surface should be approximately 12 inches to minimize blowing due to windy conditions. The pressure within the spray bar should be limited to between 10 and 20 pounds per square inch gage pressure. This pressure range is selected to reduce misting and blowaway caused by the impingement of high velocity droplets on the pavement and to maintain an even, relatively constant spray pattern from the nozzles. The nozzles should be selected based on the nozzle height above the pavement and on the nozzle spray angle. This distance between nozzles may be computed as follows (see Figure 3):

$$d = 2h \tan a/2 \qquad (2)$$

where: d = spacing between nozzles as determined by the width of the spray pattern from a single nozzle, in inches

h = height of the nozzle tip above the pavement surface, in inches

a = nozzle spray angle

TABLE 6. Pump Delivery Rates for Various Application Rates and Vehicle Speeds for a 25-Foot Boom.

Application Rate Per 1000 Sq Ft	Gallons Per Minute Delivered At MPH				
	10	15	20	30	40
4	88	132	176	-	-
2	44	66	88	132	176
1	22	33	44	66	88
0.5	11	-	22	33	44

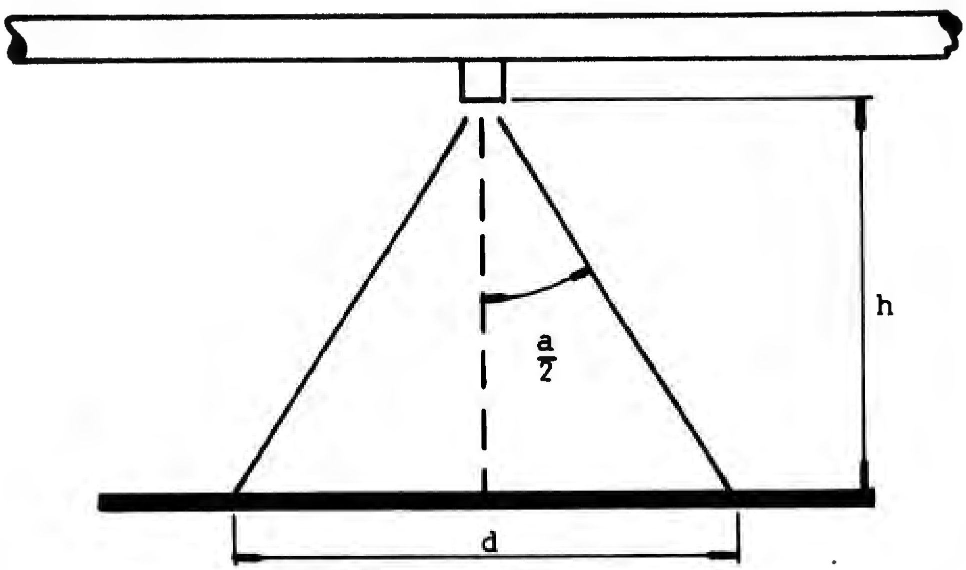


Fig. 3 Schematic of nozzle spacing relationships.

Once the nozzle spray height has been determined, the boom should be adjustable to permit a slight overlap between spray patterns. Additionally, the nozzles should be twisted slightly out of parallel with the boom to reduce interference between adjacent spray fans.

Depending on local needs, other applicator capabilities which should be considered are:

a. Fitting the applicator with an auxiliary pump to assist loading of chemical or other fluid from 55-gallon drums.

b. A manway in the top of the tank to permit cleaning and flushing of the interior.

c. Bypass pipe and valving around the positive displacement pump to permit gravity flow of fluid (other than ice control chemical in winter operations) if low pressure, high flow rate capability is required. Such an application will require temporary removal of the nozzles from the boom.

As a base studies its needs, other required capabilities will be identified by local personnel. The composite of these required capabilities may be unique with each base; however, many of these individual requirements may apply at the majority of bases. A draft purchase description should be circulated, under separate cover, to the commands which possess user potential These commands should review this purchase description and comment on their requirements.

Bulk storage and dispensing facilities for anti-icing and deicing chemicals will increase ice control operational capabilities by reducing applicator turn-around time. The applicator filling time may become quite critical during deicing operations since 6000 gallons will be required to deice the center 150 feet of a 10,000 foot runway when the application rate is 4.0 gallons of chemical per 1000 square feet. The commands should support and encourage programs for expanded or new bulk storage and dispensing facilities to meet base ice control chemical handling requirements.

SECTION V

CONCLUSIONS AND RECOMMENDATIONS

As a result of the several investigations discussed in the preceding sections of this report, it is concluded that:

a. For a surface temperature range between 15°F and 32°F, prilled urea performs better as a deicing agent than liquid chemicals when used with SIRC equipment. Without SIRC equipment, the liquid chemicals perform equally as well or better than prilled urea; however, the variability in results due to conditions of weather are fairly large.

b. For surface temperatures below 15°F, the liquid chemicals are more effective as deicing agents than urea, and they perform best when SIRC equipment is used. Variability in expected chemical effectiveness is influenced by ambiant weather situations.

c. Mechanical ice removal methods should be used to reduce the ice thickness to at least 1/4 inch, and preferably to 1/8 inch, prior to applying liquid ice control chemicals.

d. The liquid chemicals perform more predictably as anti-icing agents than as deicing agents. When applied at the rate of one gptsf, they are effective, in the 20°F to 32°F surface temperature range, in preventing the formation of ice until the dilution ration reaches eight parts water to one part chemical.

e. The USAF inventory air-blast snow sweeper is effective in removing the chemical-water slush formed as a result of anti-icing operations.

f. If freezing precipitation persists during anti-icing operations, multiple applications of chemical and use of the air-blast sweeper will be required to maintain airfield surfaces in a "bare pavement" condition.

g. Precautions should be taken to prevent unexpected, sudden deterioration of surface tractive characteristics as a result of anti or deicing chemical applications.

h. Only those liquid ice control chemicals which are listed in Qualified Products List (QPL) 83411 (chemicals which conform to MIL-D-83411), or which conform to

MIL-A-8243, should be used as runway and taxiway anti-icing and deicing agents. Aircraft anti-icing and deicing ground operations should be granted priority for MIL-A-8243 fluids over airfield ice control operation due to current (Dec 73) critical shortages in the prime component, ethylene glycol.

i. Liquid ice control chemicals should not be used on non-air entrained portland cement concretes.

j. Use of liquid ice control chemicals on air entrained portland cement concretes should be minimized commensurate with operational requirements.

k. Applications of liquid ice control chemicals on asphaltic, tar-rubber, and porous asphalt concretes should be limited by the economic balance between chemical and mechanical methods of ice removal and control.

l. All ice control chemicals are directly toxic to fish and other aquatic life at elevated concentrations. However, it is unlikely that normal or even emergency ice control operations will result in receiving water chemical concentrations which are directly toxic to aquatic life.

m. The microbial assimilation and degradation of these ice control chemicals may result in concentrations of toxic by-products or oxygen depression levels detrimental to fish and other aquatic biota.

Based on the above conclusions and the discussions contained herein, it is recommended that:

a. Bases continue to procure and use prilled urea as a deicing agent when surface temperatures range between 15°F and 30°F.

b. Bases should procure and use the MIL-D-83411 chemicals as anti-icing agents. Use as deicing agents should be limited to temperatures where urea is not effective.

c. Bases should develop local procedures to provide for testing of small areas of the surface to be treated to insure against excessive loss of traction from chemical application.

d. All bases which use ice control chemicals should maintain records of applications and their effect on traction loss and on pavement degradation, particularly

results of initial tests and exceptions to the standard ice control routine. Details of weather and icing conditions; age, type and condition of the paved surface, and time since last washing by rain or other method; and method of traction loss determination should be included.

e. The environmental consequences of the contemplated use of all chemical ice control agents should be assessed by each base and a copy of the environmental assessment included in the base snow removal plan. Additionally, efforts should be initiated to preclude detrimental environmental effects resulting from chemical ice control operations.

f. A draft purchase description for use in procuring chemical application equipment should be developed and circulated to the several commands for their review prior to finalization.

g. Bases should program for increased or new bulk storage and dispensing facilities to reduce the applicator filling time during ice control operations, particularly those involving pavement deicing.

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Appendix A

CALIBRATION OF WATER TRUCK SPRAY BAR

1. VEHICLE DESCRIPTION.

The vehicle utilized to apply water to the test surfaces during the Kincheloe AFB Ice Control Chemical Field Evaluation was borrowed from the Pavements and Grounds Section, 4609th Civil Engineering Squadron, Kincheloe AFB MI. This vehicle was a 5-ton dump truck, AF Registration No. 66C1981, which was fitted with a skid-mounted 1000 gallon tank, centrifugal pump, gasoline powered engine, 16-foot spray boom, and necessary piping and valves to permit liquid application by either gravity drain or by pressurized discharge. The tank and spraying apparatus were manufactured locally. Water application during the field portion of the evaluation program was exclusively by gravity discharge.

2. MODIFICATION.

Modification of this vehicle or its water distribution system was not required.

3. CALIBRATION.

Calibration of this equipment was based on an estimate of the discharge rate during a timed period and was performed as follows:

a. The water tank was filled to a little over half full and water was permitted to discharge under gravity pressure for a period of two minutes. The depth of water in the tank immediately before and after discharge was measured. Other pertinent dimensions of the water volume discharged were obtained (see Figure A-1).

b. The volume of water discharged during the timed period was found to be 76 gallons by the following formula:

$$V_w = (0.00434) \left(\frac{W_o+W_2}{2}\right) (d_o-d_2)L \qquad \text{(A-1)}$$

where: V_w = the volume of water discharged, in gallons

W_o = the width of the water surface at time zero, in inches

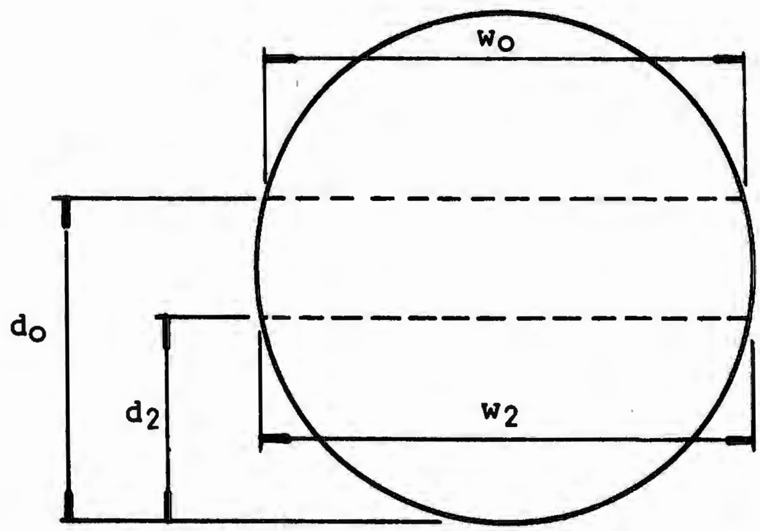
W_2 = the width of the water surface after the two minute discharge period, in inches

d_o = the depth of water within the tank at time zero, in inches

d_2 = the depth of water within the tank after the two minute discharge period, in inches

L = the length of the water tank, in inches

0.00434 = a factor to convert cubic inches of water to gallons, in gallons per cubic inch



$L = 71''$

$d_o = 43''$

$d_2 = 39''$

$w_o = 60.5$

$w_2 = 63''$

$\Delta t = 2$ min

Figure A-1

c. The average application rate of the spray boom was computed using the formula:

$$A = \frac{V_w}{\Delta t} \qquad \text{(A-2)}$$

where: A = the spray boom application rate, in gallons per minute

Δt = the lapsed time, in minutes

V_w = defined above

The application rate was thus found to be 38 gpm.

d. The application rate, in gallons per 1000 square feet, for various truck velocities was subsequently determined with the aid of the following formula and the results are tabulated below:

$$R_D = \frac{1000A}{WV_v} \qquad \text{(A-3)}$$

where: R_D = the desired water application rate, in gallons per 1000 square feet (gptsf)

A = defined above

W = the width of the water application by the spray boom, in feet (16 feet)

V_v = the vehicle velocity, in feet per minute

Vehicle Velocity mph	Vehicle Velocity V_v, fpm	Application Rate R_D, gptsf
1	88	27.0
3	264	9.0
4	352	6.7
6	528	4.5
10	880	2.7

e. Since the water distribution truck was not equipped with a fifth wheel mechanism to indicate true vehicle velocity, water application velocities had to be judged from those indicated by the truck speedometer. To check the accuracy of the vehicle's speedometer, timed runs over a measured distance were required. Results of these checks are as follows:

Indicated Velocity mph	Timed Velocity mph
6	5.95
10	10.00

Based on these results, no correction to the velocities indicated by the vehicle speedometer was required.

Appendix B

MODIFICATION AND CALIBRATION OF ASPHALT DISTRIBUTOR

1. VEHICLE DESCRIPTION.

The asphalt distributor, AF Registration No. 69D345, assigned to the AFCEC, was a new vehicle when used during the Phase II portion of the test. The chassis was equipped with a Littleford Bituminous Materials Distributor, Model "S King." The system includes an 800 gallon tank, a 400 GPM positive displacement pump, transmission, clutch, gasoline pump engine, spray boom and necessary piping, valves, gauges and linkages normally found on commercial equipment of this type.

2. MODIFICATION.

The only modification made to the asphalt distributor was to the spray boom of the distributor.

a. The spray boom was extended, using the accompanying boom extension sections, to 20 feet.

b. The standard asphalt spray nozzles were removed from the spray boom and three out of four nozzle outlets were plugged.

c. At every fourth nozzle outlet, appropriate nipples and reducers were installed to permit the attachment of Tee Jet, Flat Spray Nozzles, Tip #8010 (source: Catalog #35, Spraying Systems Co, 3201 Randolph St, Bellwood, Ill 60104), rated as follows:

Water Pressure PSI	Capacity Per Nozzle GPM
20	0.70
25	0.78
30	0.86
40	1.00
50	1.11
60	1.22

Fifteen of these agricultural type spray nozzle and tips were fitted to the spray boom of the vehicle.

d. The spacing between spray tips was 16 inches, center to center. This spacing provided for 20.0 feet of spray coverage when the height of the tip above the paved surface was 9.5 inches.

3. CALIBRATION.

The modified asphalt distributor was calibrated as follows:

a. A 55 gallon drum of water was transferred to the 800 gallon vehicle tank.

b. The pump engine was started, the throttle was set at idle (the lowest rpm setting) and the transmission was placed in first gear. The clutch was then engaged.

c. As the pump began operating, the operation selector was turned from "Bar Circulate" to "Spray." A few seconds delay was required to purge the air from the spray boom. Once the air had been cleared from the spray boom, the time was recorded. Time was again recorded once it was evident that the system was pumping mostly air.

d. This procedure was repeated three times and an average time to discharge 55 gallons was determined. This average was found to be three minutes, 19 seconds (199 seconds). Accordingly, the spray boom was distributing water at the rate of 16.6 gallons per minute over a 20 foot spray pattern.

e. The vehicle velocities for the various applications rates were then calculated using the following formula:

$$V_V = \frac{A}{R_D W} \tag{B-1}$$

where: V_V = the vehicle velocity in feet per minute

A = the spray boom application rate (16.6 gallons per minute)

R_D = the desired liquid application rate in gallons per square foot

W = the length of the spray boom (20 feet)

The results of these calculations are as follows:

R gpsf	V_v fpm
1/2000	1660 (18.8 mph)
1/1000	830
1/750	622
1/500	415
1/250	207

f. The fifth-wheel velocity indicator could then be set to the velocity required for the proper application rate. Since the maximum velocity which the velocity indicator could measure was 1500 feet per minute, it was necessary to use the asphalt distributor's speedometer when chemical was applied at the rate of 1 gallon per 2000 square feet. To insure that the speedometer was reasonably accurate at this speed, the vehicle was timed over a measured test area (900 feet in length) at 20 mph. The results of this timed distance run indicated that the speedometer was sufficiently accurate and within 5 per cent error. It was agreed that accelerator pedal control would probably account for a greater error in vehicle velocity than 5 per cent.

4. DISCUSSION.

This method of calibrating the Phase II chemical application equipment was one of four methods considered. The other methods and the reasons they were not chosen were:

a. To determine the difference in truck weight after the spray boom had been operated for a timed period. This was the preferred method. Unfortunately, the only truck scales on Kincheloe AFB were buried beneath a rather deep snow bank and its condition could not be readily determined.

b. To determine the quantity of fluid remaining in the 800 gallon tank after a timed period by "sticking" the tank. This method was discarded since the gradations on the "stick" provided with the tank were marked off in 10 gallon increments, and it was felt that the probability and magnitude of errors involved were too great.

c. To determine the quantity of fluid pumped through the spray boom during a timed period. This method was not used since the collection system would have to be fabricated. It was originally hoped that sheet metal guttering material could be found at Kincheloe AFB and this material borrowed for the duration of the test. After contacting BCE and base supply personnel, it was learned that such guttering material was not available.

Appendix C

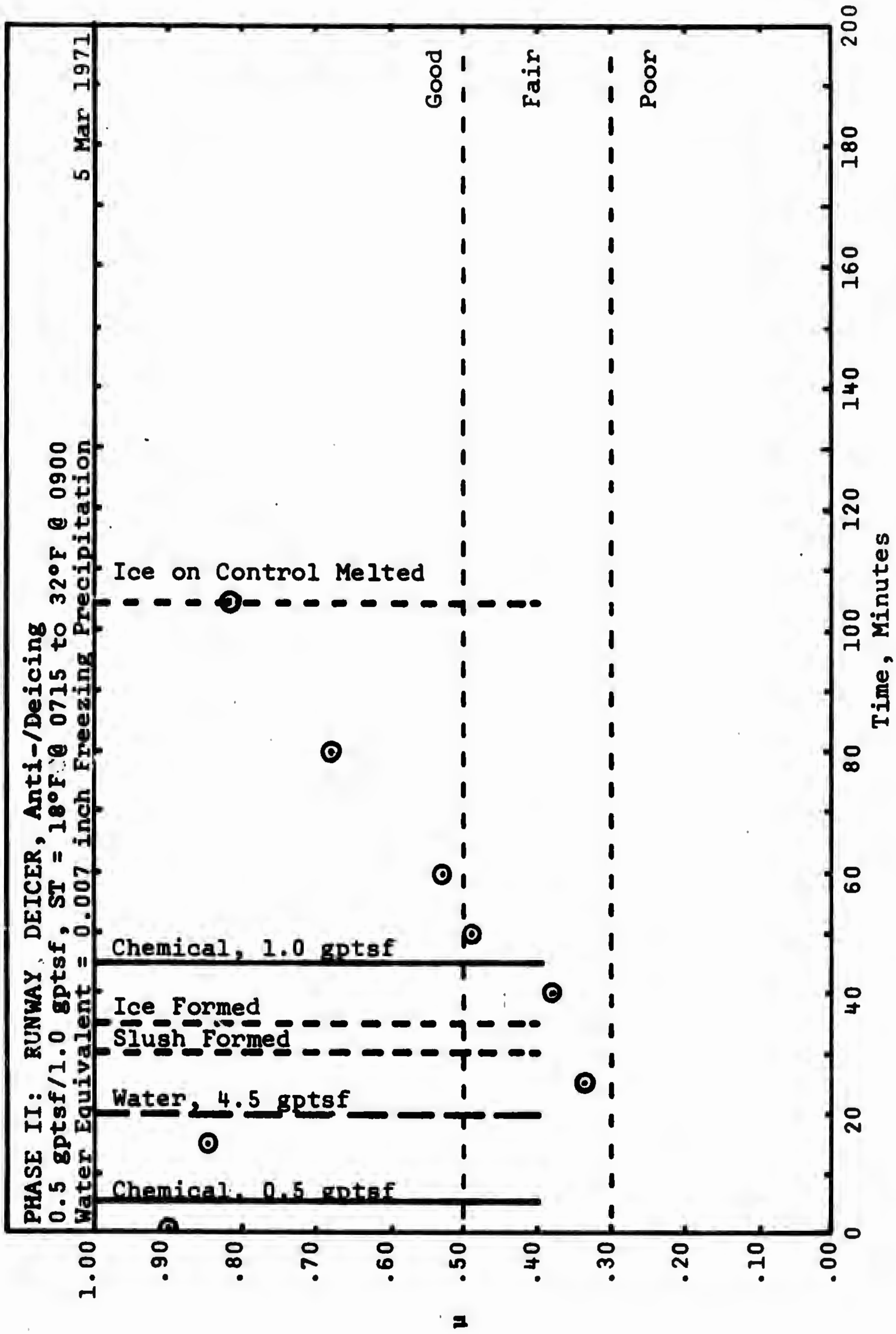
ANALYSIS OF POTABLE WATER SUPPLY KINCHELOE AFB, MICHIGAN

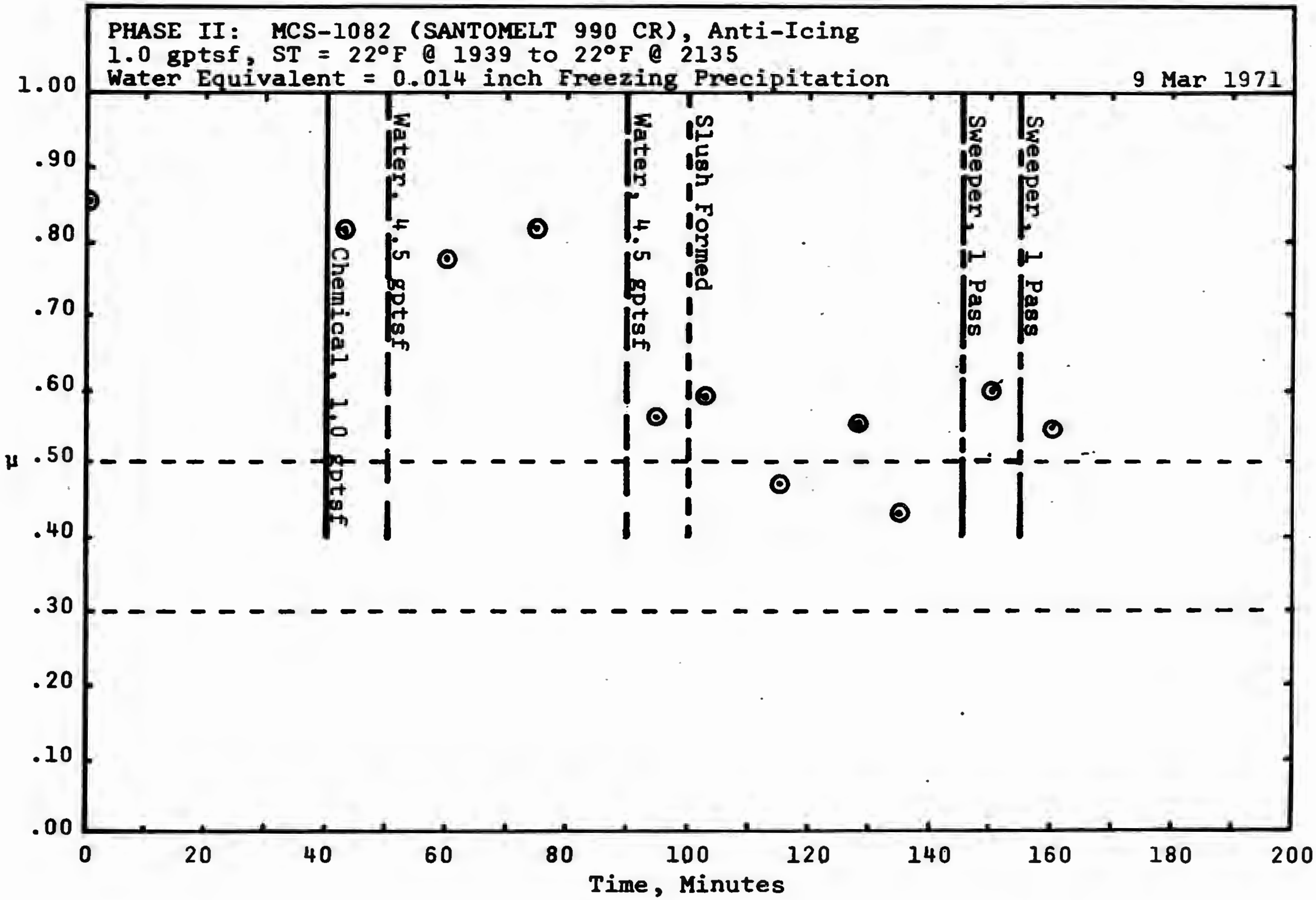
Analysis performed by the Geological Survey, United States Department of the Interior, on ten (10) samples collected on 23 June 1969. All values reported as milligrams per liter, except where otherwise noted. Water sources at Kincheloe AFB are deep wells, and treatment prior to distribution is limited to chlorination.

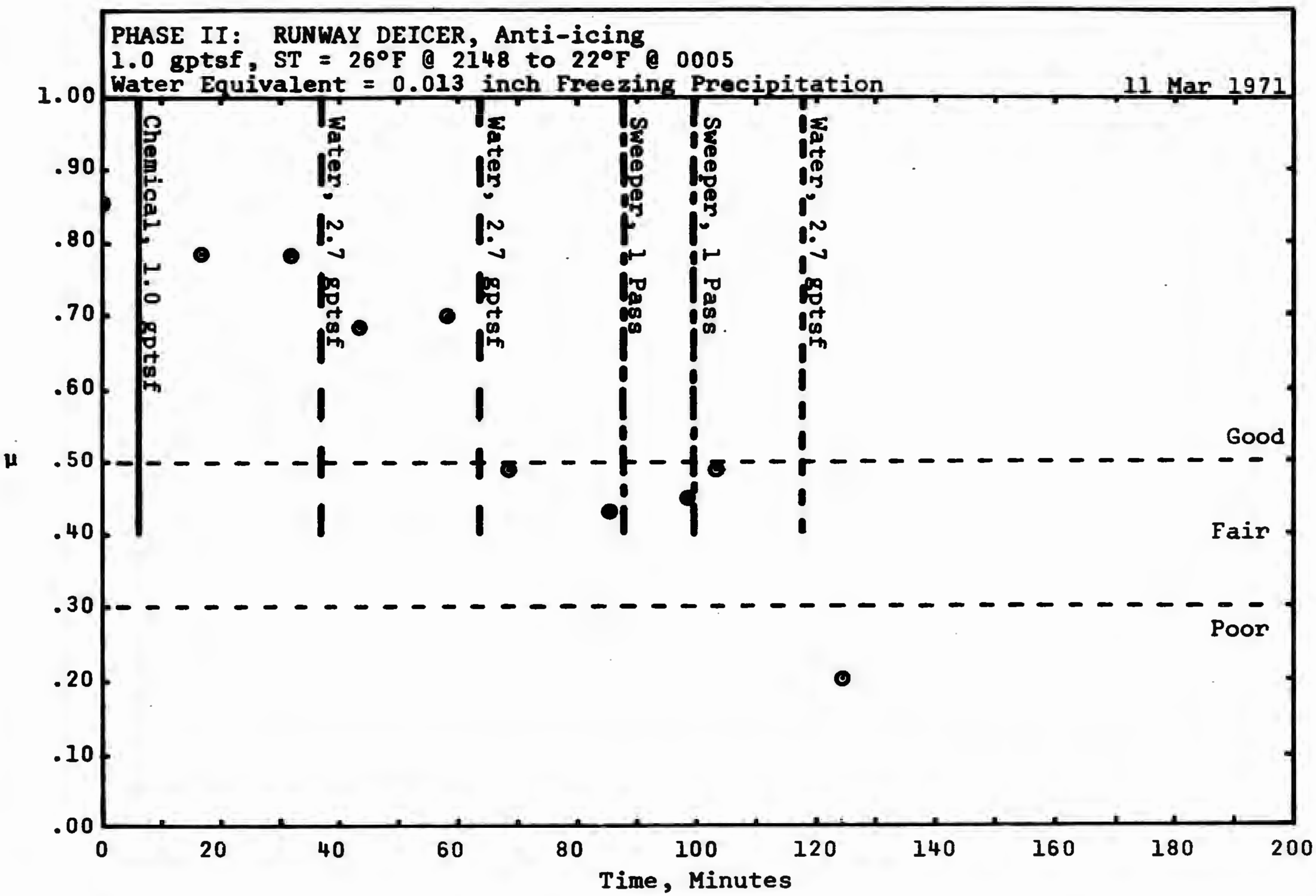
ITEM OF ANALYSIS	AVERAGE OF SAMPLES, mg/l	
	BEFORE TREATMENT	AFTER TREATMENT
Silica (SiO_2)	12.33	11.18
Iron (Fe)	.04	.01
Manganese (Mn)	.03	.01
Calcium (CA)	32.83	27.25
Magnesium (Mg)	12.57	10.90
Sodium (Na)	3.65	2.45
Potassium (k)	.73	.68
Bicarbonate (HCO_3)	138.67	108.50
Carbonate (CO_3)	-0-	-0-
Sulfate (SO_4)	13.47	12.43
Chloride (CI)	6.42	6.38
Fluoride (F)	.10	.88
Nitrate (NO_3)	4.62	3.10
Dissolved Solids		
Calculated	154.67	128.50
Residue on evaporation at 180°C	160.17	135.25
Hardness as $CaCO_3$	133.83	113.25
Noncarbonate hardness as $CaCO_3$	19.83	24.75
Alkalinity as $CaCO_3$	113.67	88.75
Carbon Dioxide, (CO_2) Calc.	2.18	2.08
Specific Conductance (Micromhos at 25°C)	268.83	229.00
pH (pH Index)	8.05	7.98
Color (Scale unknown)	2.00	1.50
Temperature (°C)	11.00	11.25

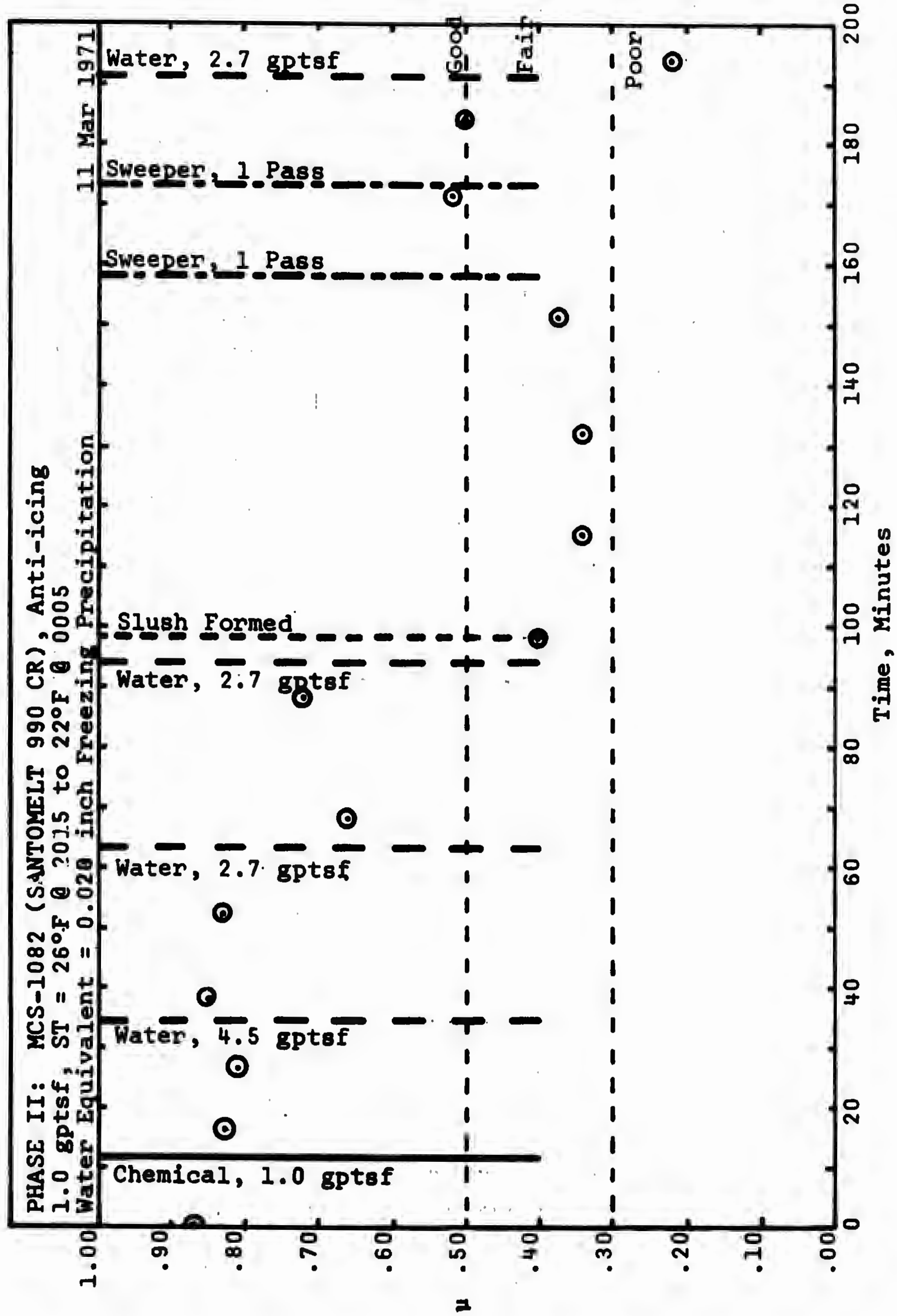
Appendix D

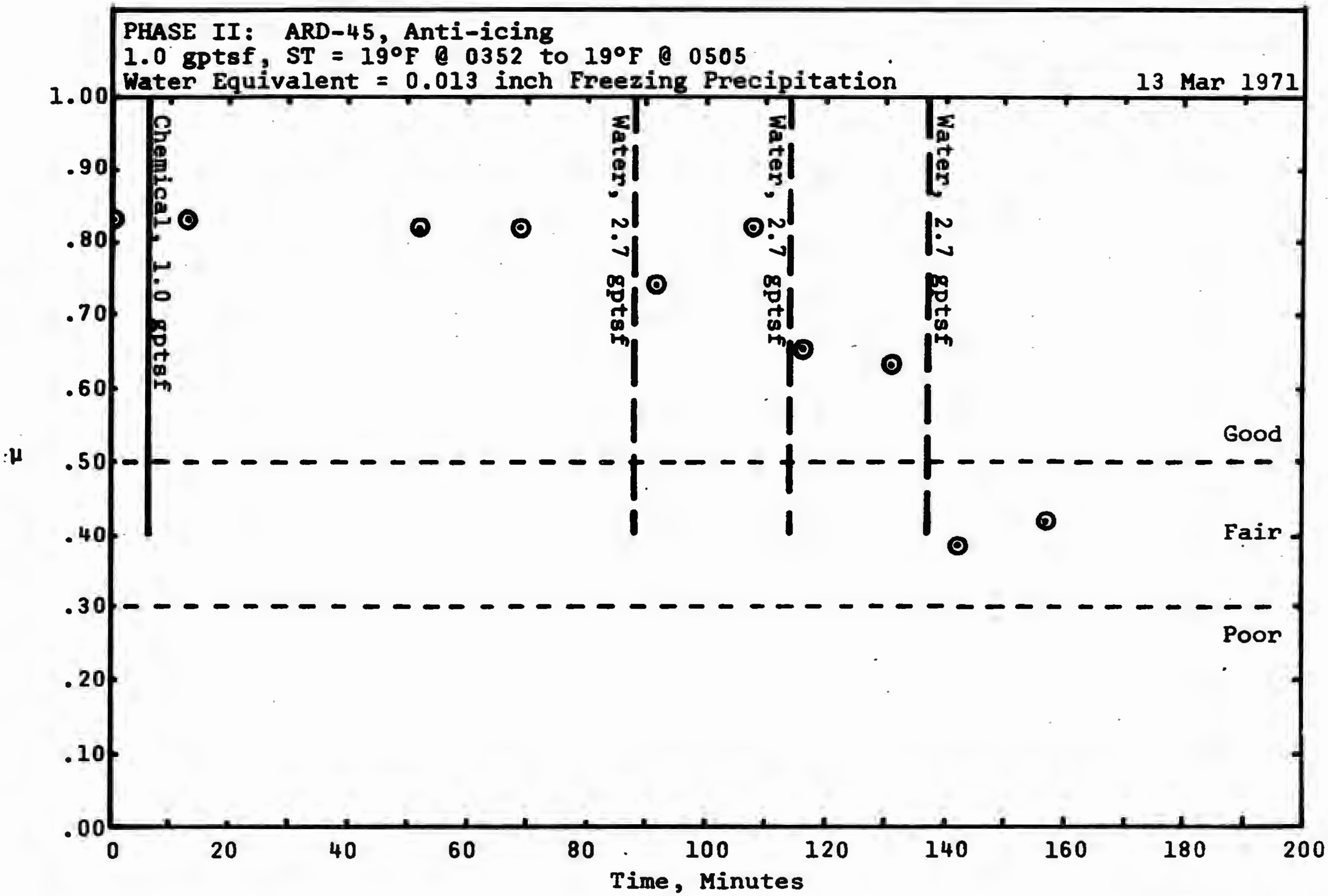
ANTI-ICING TEST CHRONOLOGIES

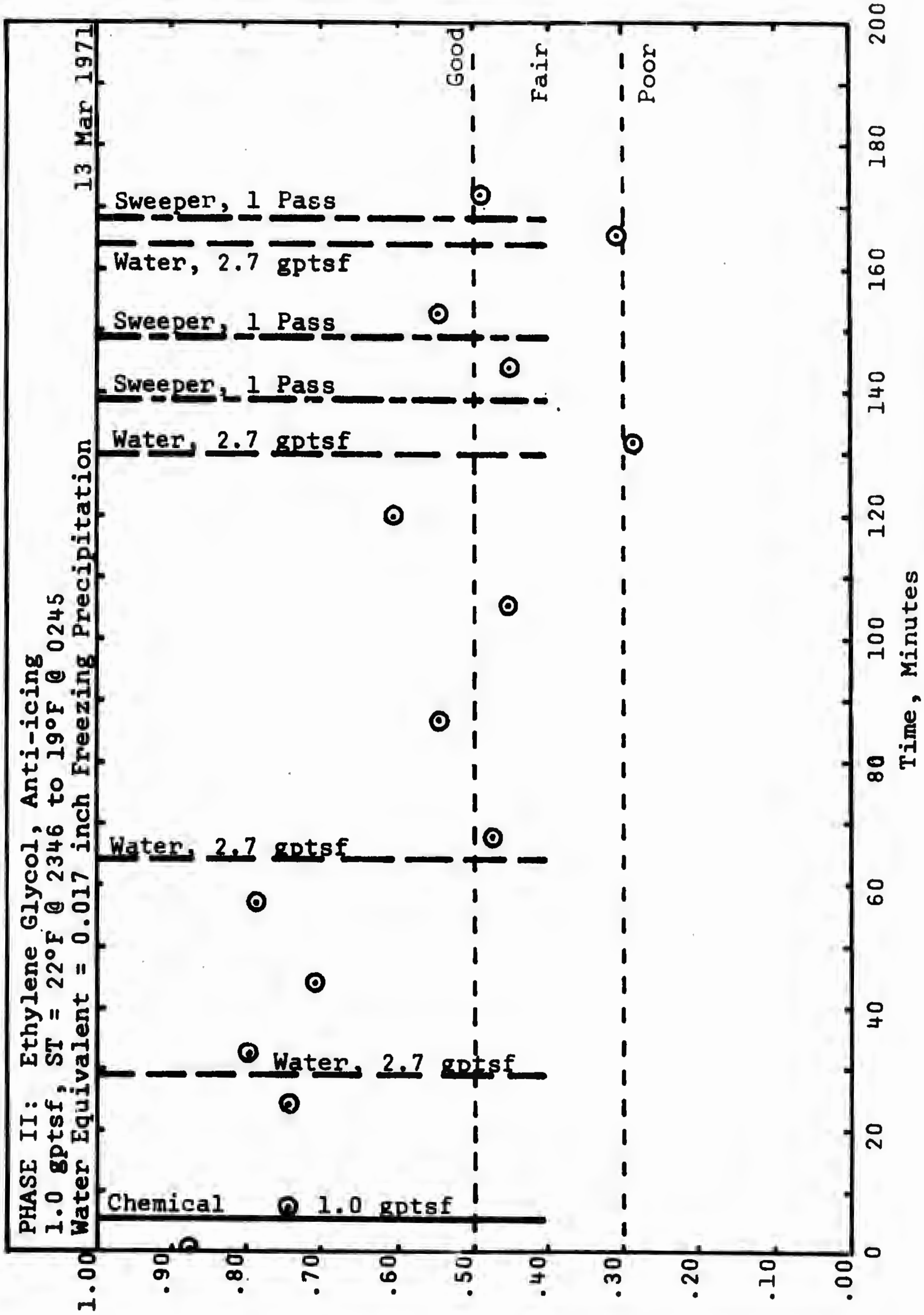

PHASE II: RUNWAY DEICER, Anti-/Deicing
0.5 gptsf/1.0 gptsf, ST = 18°F @ 0715 to 32°F @ 0900
Water Equivalent = 0.007 inch Freezing Precipitation
5 Mar 1971
Good
Fair
Poor
Ice on Control Melted
Chemical, 1.0 gptsf
Ice Formed
Slush Formed
Water, 4.5 gptsf
Chemical, 0.5 gptsf
0
20
40
60
80
100
120
140
160
180
200
Time, Minutes
1.00
.90
.80
.70
.60
.50
.40
.30
.20
.10
.00
µ


PHASE II: MCS-1082 (SANTOMELT 990 CR), Anti-Icing
1.0 gptsf, ST = 22°F @ 1939 to 22°F @ 2135
Water Equivalent = 0.014 inch Freezing Precipitation
9 Mar 1971
Chemical, 1.0 gptsf
Water, 4.5 gptsf
Water, 4.5 gptsf
Slush Formed
Sweeper, 1 Pass
Sweeper, 1 Pass
μ
1.00
.90
.80
.70
.60
.50
.40
.30
.20
.10
.00
0
20
40
60
80
100
120
140
160
180
200
Time, Minutes


PHASE II: RUNWAY DEICER, Anti-icing
1.0 gptsf, ST = 26°F @ 2148 to 22°F @ 0005
Water Equivalent = 0.013 inch Freezing Precipitation
11 Mar 1971
Chemical, 1.0 gptsf
Water, 2.7 gptsf
Water, 2.7 gptsf
Sweeper, 1 Pass
Sweeper, 1 Pass
Water, 2.7 gptsf
Good
Fair
Poor
μ
1.00
.90
.80
.70
.60
.50
.40
.30
.20
.10
.00
0
20
40
60
80
100
120
140
160
180
200
Time, Minutes


PHASE II: MCS-1082 (SANTOMELT 990 CR), Anti-icing
1.0 gptsf, ST = 26°F @ 2015 to 22°F @ 0005
Water Equivalent = 0.028 inch Freezing Precipitation
11 Mar 1971
Chemical, 1.0 gptsf
Water, 4.5 gptsf
Water, 2.7 gptsf
Water, 2.7 gptsf
Slush Formed
Sweeper, 1 Pass
Sweeper, 1 Pass
Water, 2.7 gptsf
Good
Fair
Poor
μ
1.00
.90
.80
.70
.60
.50
.40
.30
.20
.10
.00
0
20
40
60
80
100
120
140
160
180
200
Time, Minutes


PHASE II: ARD-45, Anti-icing
1.0 gptsf, ST = 19°F @ 0352 to 19°F @ 0505
Water Equivalent = 0.013 inch Freezing Precipitation
13 Mar 1971
μ
1.00
.90
.80
.70
.60
.50
.40
.30
.20
.10
.00
Chemical, 1.0 gptsf
Water, 2.7 gptsf
Water, 2.7 gptsf
Water, 2.7 gptsf
Good
Fair
Poor
0
20
40
60
80
100
120
140
160
180
200
Time, Minutes


PHASE II: Ethylene Glycol, Anti-icing
1.0 gptsf, ST = 22°F @ 2346 to 19°F @ 0245
Water Equivalent = 0.017 inch Freezing Precipitation
13 Mar 1971
Sweeper, 1 Pass
Water, 2.7 gptsf
Sweeper, 1 Pass
Sweeper, 1 Pass
Water, 2.7 gptsf
Water, 2.7 gptsf
Water, 2.7 gptsf
Chemical 1.0 gptsf
Good
Fair
Poor
1.00
.90
.80
.70
.60
.50
.40
.30
.20
.10
.00
μ
0
20
40
60
80
100
120
140
160
180
200
Time, Minutes

ABBREVIATIONS AND SYMBOLS USED

Abbreviation/ Symbol	Definition
SIRC	Snow and Ice Removal and Control
AFCEC	Air Force Civil Engineering Center
AFML	Air Force Materials Laboratory
gptsf	gallons per 1000 square feet
CRREL	The US Army Cold Regions Research and Engineering Laboratory
PONYA	Port of New York Authority
MOT	Canadian Government's Ministry of Transport